

Research Article

Avian composition in the rural ‘Amazon Front Yard’ still retains its humid tropical identity

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Abstract

The Bragantina region is one of the most densely settled regions of the Amazon Basin. Rainforests were clear-cut during the last two centuries and replaced by a tessellated rural landscape of pastures, fields, oil palm plantations, gallery forests, and secondary vegetation. However, the impact of the still ongoing land-use changes on biodiversity has hardly been studied, so the purpose of this paper is to summarize bird observations from the Belém area and its rural hinterland. Audiovisual bird surveys were carried out around Belém, on ten farms in the municipality of Igarapé-Açu, and along the Atlantic coast between 1999 and 2018. Compiled species lists are compared with historical studies of the Bragantina, adjacent Maranhão, and Marajó. To evaluate regional community assembly, non-metric multidimensional scaling (NMDS) was employed and beta diversity was partitioned into turnover and nestedness components. Results indicate that community differentiation is primarily driven by species turnover (replacement) rather than nestedness (species loss), reflecting a significant ecological shift while maintaining high regional richness. Species diversity was further analyzed using Hill numbers ($q = 0, 1, 2$) and integrated rarefaction/extrapolation curves to ensure robust regional comparisons independent of sampling effort. In total, 300 bird species (220 genera; 62 families) were reconfirmed. Although the mosaic-like landscape resembles savannas today, the data elucidate that bird composition is still more similar to that of the ancient rainforest biome than to that of adjacent savannas. While robust, widespread neotropical generalists, such as *Crotophaga ani* and *Columbina passerina*, became dominant, and *Guira guira* and *Melanerpes candidus* established themselves, large understory game birds of pristine rainforests are virtually absent. However, endemic canopy species, such as *Xipholena lamellipennis*, might survive within the Bragantina if sufficiently large forest patches and mast trees are protected and planted at regular intervals across the whole region. Thereby, it may be more promising to protect robust, common (to rare) Amazonian bird species that can follow dynamic land-use changes than to concentrate on the last remaining pristine forest specialists.

Key words: Amazonia, Bragantina, Igarapé-Açu, rural landscape, savannization, waterfowl**Academic editor:**

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Introduction

Belém do Pará is frequently referred to as the “Gateway to the Amazon,” as it represents a principal point of entry for tourists, naturalists, and scientists approaching the Amazon from the eastern Brazilian side (PMdB 2024).

Indeed, numerous scientific expeditions and research initiatives focused on the Amazon Basin establish their logistical base in this metropolis of over two million inhabitants before proceeding through the “Gateway” into the world’s largest expanse of tropical lowland rainforest. Despite decades of research, the Amazon remains insufficiently surveyed or monitored, largely due to its immense size, ecological complexity, blessed biodiversity, wilderness, and limited accessibility (Silva et al. 2005; Lees et al. 2012). This lack of comprehensive knowledge applies even to birds, one of the globally best-studied vertebrate groups. Consequently, contemporary research has concentrated on old undisturbed forest areas deeper within the Amazon Basin, particularly west of Belém (Pacheco et al. 2007). By contrast, the “Amazon Front Yard”—the eastern hinterland of Belém, known as the Bragantina region—has been largely neglected by both conservation efforts and scientific biodiversity inquiry. This region has undergone extensive deforestation and land-use transformation for agricultural purposes for over 125 years (Metzger 2002; Hohnwald et al. 2010). As a result, it is often presumed to be of limited relevance for biodiversity research, and scientific publications or ecological data concerning the area are exceedingly scarce. In response to this knowledge gap, the present study provides original field observations on the avifauna of the Belém area and its surrounding rural landscape, with the aim of contributing to a more nuanced understanding of biodiversity patterns of the “Amazon Front Yard.”

The Bragantina region belongs to the humid tropics of northern Brazil, specifically at the northeastern margin of the Amazon Basin, in an area often referred to as the NE-Amazon. The region’s potential natural vegetation is thereby the evergreen lowland tropical rainforest, renowned for its blessed biodiversity in both plant and animal life (Hohnwald et al. 2015; de Moraes et al. 2020). However, moving just 100 km southeast from the town of Viseu do Pará, the dry season becomes more pronounced, and the landscape transitions into the semi-humid tropics, marking the northern extent of the Brazilian savanna biome. The first natural stands of Babaçu palms (*Attalea speciosa* Mart. ex Spreng., Arecaceae), for instance, have been documented in Turiaçu, located in northwestern Maranhão, approximately 260 km southeast of Igarapé-Açu. Further to the east-southeast, just 500 km from the Bragantina, begins the semi-arid biome of the Caatinga. Biogeographically, the Bragantina region corresponds to the so-called Belém Center of Endemism (BCE), a zone that harbors a limited number of true endemic species but does include several distinctive subspecies (de Almeida and Vieira 2010; Silva et al. 2005; Oliveira et al. 2017). Notably, a substantial proportion of the Amazonian biome’s “threatened” bird taxa are primarily confined to the BCE (Moura et al. 2014; de Moraes et al. 2024). Fortunately, the region has a long history of ornithological research, extending back over two centuries, with major collection efforts taking place during the second half of the nineteenth century (Novaes and Lima 2009; Portes et al. 2011). Forrester’s (1993) regional checklist, which also covers the upstate of Belém, provides foundational data on the abundance, migratory behavior, and historical records of bird species and serves as a key reference for the present study. Altogether, approximately 529 bird species have been recorded in northeastern Pará, of which around 329 were found in *terra firme* forest near Belém (Novaes and Lima 2009; Moura et al. 2014; Aleixo 2025).

It is often disregarded that the Humid Tropics of the Amazon/Orinoco Basins include an Atlantic coastline stretching over 2,400 km, not accounting for the extensive perimeters of bays and islands. This coastal arc extends from São Luís in Maranhão (Brazil) to Trinidad and the Turuépano National Park in north-eastern Venezuela (Rodrigues 2007). Within this broader context, the Bragantina region encompasses a substantial portion of the Atlantic coastline, known as the *Salgado paraense*. This littoral zone is characterized by wide sandy beaches, extensive mangrove forests, *restinga* vegetation, and sand dunes, yet its coastal avifauna remains relatively poorly documented (Lees et al. 2014). The so-called *Reentrâncias paraenses*—a complex of deeply indented coastal inlets and estuaries—have increasingly been subjected to pressures from weekend tourism and mass beach recreation, often accompanied by noise pollution and infrastructure development (Souza Filho 2013). Despite these disturbances, approximately 247 bird species have been reported from the *Salgado paraense*, particularly along the beaches of Atalaia, Praia da Corvina, and Salinópolis–Maçarico (Kober and Bairlein 2006; Lees et al. 2014). These species are also found along both shores of Guanabara Bay, including the eastern coast of Marajó Island, which shares similar land-use patterns and ecological conditions with the Bragantina. The avifauna in these areas is typically associated with environments ranging from brackish estuaries to freshwater habitats.

Tropical rainforests in the NE-Amazon, including coastal areas, have undergone significant land-use transformations over the past century and continue to be affected by the expansion of more intensive agricultural systems. Native vegetation and associated bird communities have been forced to adapt to traditional slash-and-burn agriculture, resulting in the persistence of only the most disturbance-tolerant plant and animal species. Consequently, vegetation types have become less distinct and more structurally homogenized (de Almeida and Vieira 2010). This vegetation, locally known as *capoeira*, has been the subject of extensive research due to its importance as the ecological foundation of regional smallholder agriculture (Metzger 2002; Hohnwald et al. 2010).

Today, the Bragantina is characterized as an extensively cultivated mosaic composed of *capoeiras* at various successional stages, smallholder agroforestry systems (homegardens), diverse fruit tree assemblages, and staple crop fields—predominantly rice, cassava, and beans (Fig. 1; Metzger 2002; Krummel et al. 2008; Hohnwald et al. 2010, 2015). Since the 1980s, smallholder farmers have increasingly implemented pastureland, contributing to the *pecuarização* (expansion of cattle ranching) of the Bragantina. This trend reflects the broader northward shift of cattle production in Brazil over recent decades (Coy and Neuburger 2002). More recently, oil palm (*Elaeis guineensis* Jacq.) plantations have been established, further increasing the proportion of monocultures and reducing habitat heterogeneity (Hohnwald et al. 2010). This process of land-use change, involving massive structural transitions toward a much more open landscape, is referred to as savannization in this study (Nobre et al. 2016; Lovejoy and Nobre 2018). This structural simplification mimics the physiognomy of a savanna even before a full climatic biome shift is completed (Metzger 2002; Staver et al. 2011).

Projections of regional climate change indicate a trend toward hotter and drier conditions in the NE-Amazon by the end of this century (Malhi et al. 2008; Staver et al. 2011). These changes could accelerate processes of savanniza-

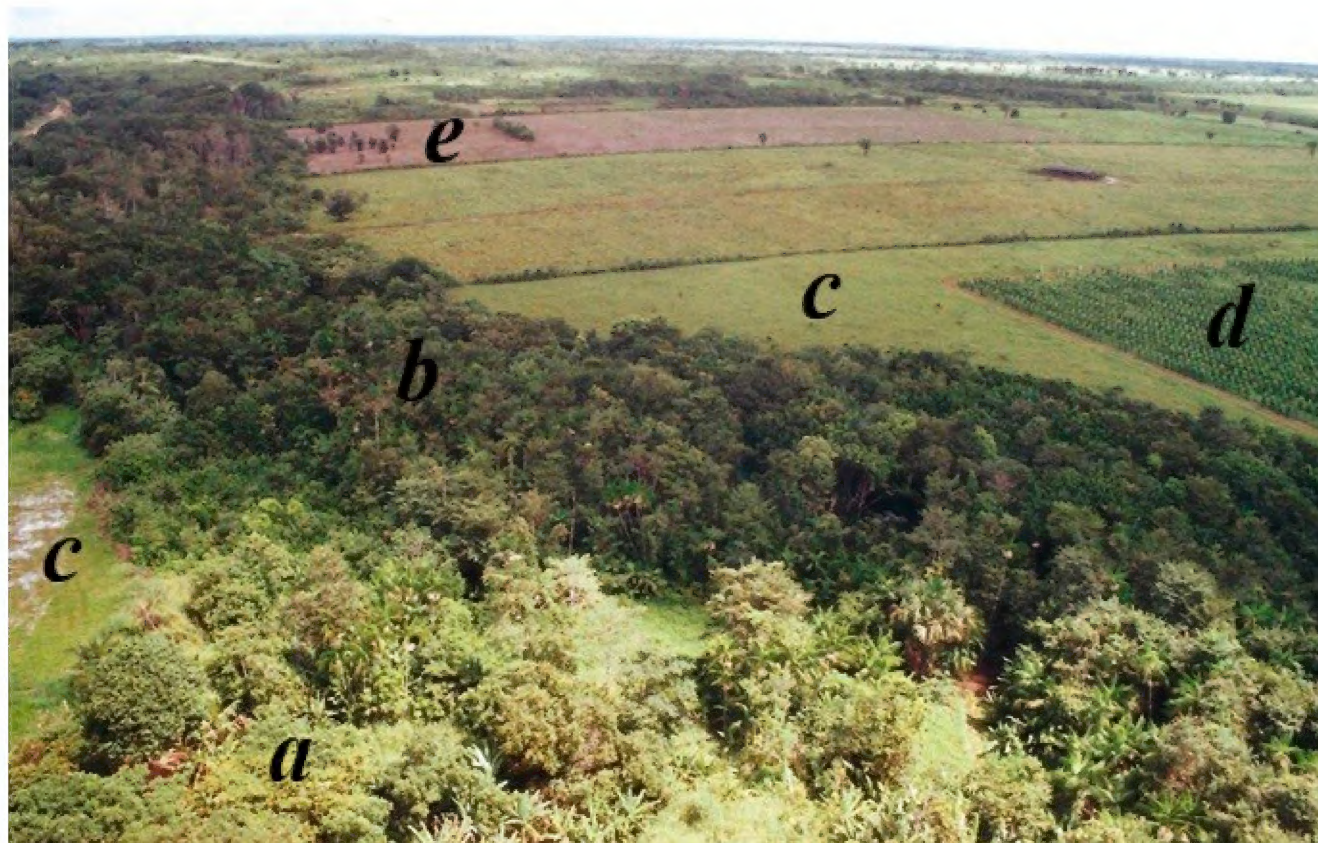


Figure 1. Tessellated landscape in the Bragantina region (Igarapé-Açu, 1°07'42"S, 47°34'42"W, October 2006): **a.** secondary vegetation (*capoeira*); **b.** gallery forest (*igapó*); **c.** pastures; **d.** pepper plantation; **e.** cassava field.

tion or ecological transformation toward drier, savanna-like ecosystems (de Moraes et al. 2020, 2024). Comparable dynamics are also observable south of the Guamá River in the Tomé-Açu region, although to a lesser extent and with slower deforestation rates. Consequently, biodiversity levels in that area remain comparatively higher (Portes et al. 2011). However, landscapes once cleared by fire and agricultural activities do not easily revert to rainforest (Staver et al. 2011).

This raises biogeographic and conservation questions: Are native rainforest species adapting to these global changes, or are savanna-associated species expanding their range and gradually replacing them? Given their high mobility and sensitivity to habitat structure, birds can respond rapidly to environmental change by relocating to more suitable habitats within the landscape. Consequently, shifts in species composition may occur within relatively short timescales. The aim of this study, therefore, is to evaluate whether the avian community still reflects its rainforest origin or whether it has already undergone a biome shift. Accordingly, it is hypothesized that, due to ongoing land-use intensification and climate-driven ecological shifts, the avifauna of the Bragantina region has already shifted toward a savanna ecosystem.

Methods

Field methods

To test this hypothesis and provide an overview of the bird diversity in the rural Bragantina region, own field observations were compiled and compared with available data from the historical rainforest avifauna (Belém list of Forrester 1993) as well as from adjacent savanna regions, including Maranhão (Oren 1991) and São Luís (Forrester 1993). This study draws upon data collected alongside three agroecological research projects conducted in the municipality of Igarapé-Açu:

1. the SHIFT-Pecuária project (February 1999–February 2001),
2. the Pasture Degradation Project (January 2006–February 2009),
3. the Carbiocial project (sporadically between 2011 and 2018).

These projects enabled long-term, on-farm field observations under real agricultural conditions. Bird surveys were carried out using standard audio-visual methods with 10 × 42 mm binoculars. Observations took place almost weekly, typically during agricultural fieldwork or weekend excursions, the latter using point-stop counts. For the farm and beach locations, this study utilizes a high-intensity on-farm census, where observations were conducted continuously during daily fieldwork cycles from 07:30 to 16:00, ensuring a comprehensive capture of avian activity across various micro-habitats and weather conditions. This long-term immersion allowed for a cumulative sampling effort that far exceeds typical standardized protocols. Species taxonomy follows Global Biodiversity Information Facility (GBIF) and Lepage (2025), and distributions were verified using IUCN (2024) data. During the first two projects, ten different farms were regularly visited for both agricultural and ornithological investigations (Fig. 2). Farm A corresponds to site 1 in Hohnwald (2009), extended here by ten additional observation days. Farm C represents site 2, and site 3 refers to Igarapé-Açu city both expanded with 12 additional observation days each. Coastal observations in the *Salgado paraense* included brackish and saltwater habitats at Algodoal Island (species list 9; Table 1), Salinópolis (species list 10 – Maçarico, and 11 – Atalaia), the Pântanos da Salinas (list 12), and Ajuruteua Beach near Bragança (list 13). At Maçarico Beach, observations were conducted twice daily, typically along

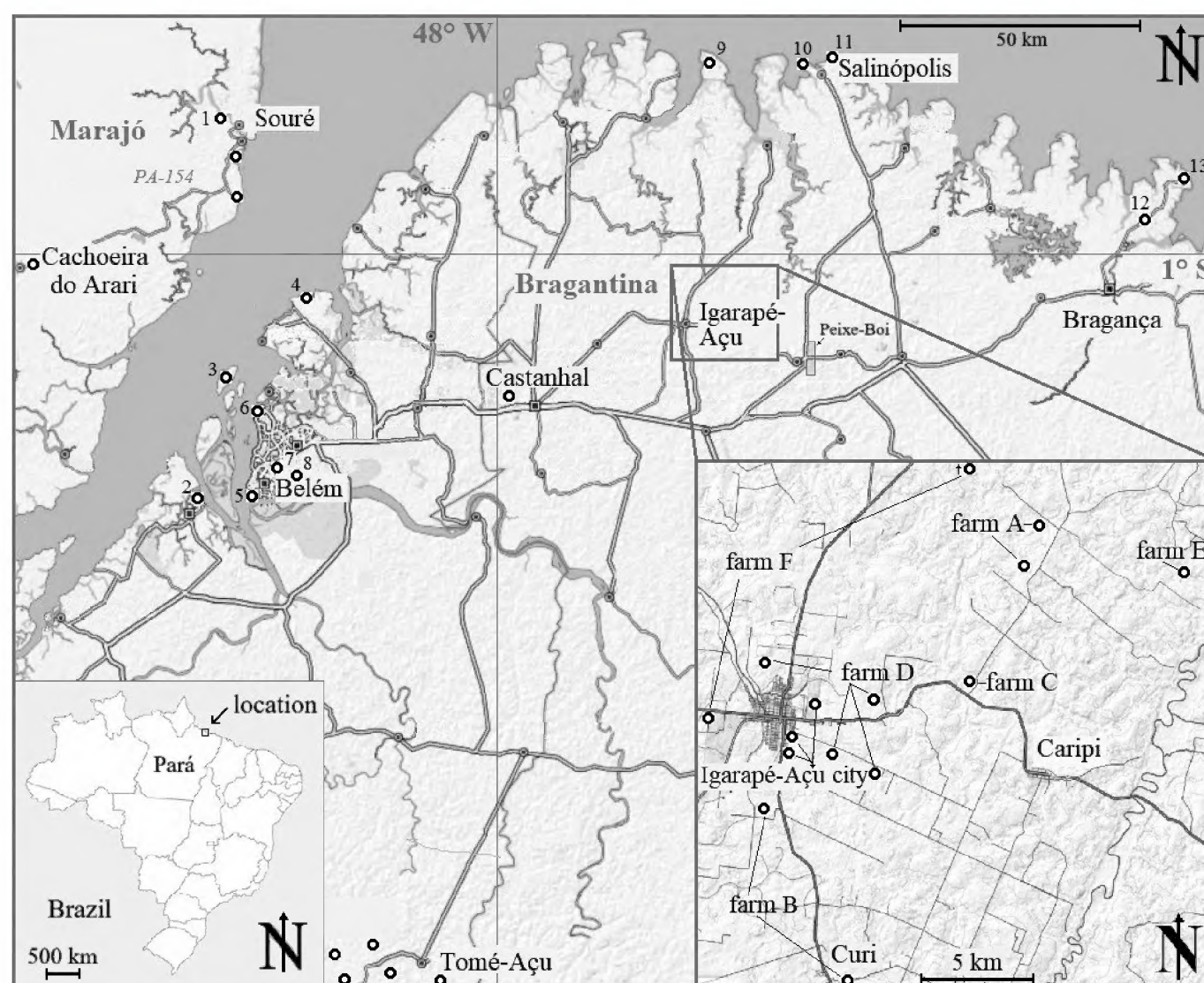


Figure 2. Locations of bird surveys. 1. BAVAM buffalo farm (Embrapa); 2. Barcarena; 3. Cotijuba; 4. Mosqueiro; 5. Mangal das Garças Park (Belém); 6. Icoaraci; 7. Belém city; 8. Embrapa; 9. Algodoal; 10. Salinópolis–Maçarico; 11. Salinópolis–Atalaia Beach; 12. Pântanos da Salinas; 13. Ajuruteua Beach.

Table 1. Classification and hierarchical organization of the study locations. Data lists (numbers according to locations in Fig. 2) are grouped into sites (used for site-specific analyses in Figs 3, 4) and aggregated regions (used for regional comparisons and biome references in Figs 5, 6), for comparison with the complete species lists of São Luís, the Bragantina (Forrester 1993), and Maranhão (Oren 1991).

Species lists	Site (Figs 3, 4)	Region (Figs 5, 6)
	farms A-F	Igarapé-Açu
	Igarapé-Açu city	Igarapé-Açu
1-Marajo	Marajo	Coast
2-Barcarena	river islands	Coast
3-Cotijuba	river islands	Coast
4-Mosqueiro	river islands	Coast
5-Mangal	Belém-City	Belém
6-Icoaraci	Belém-City	Belém
7-Marco	Belém-City	Belém
8-Embrapa	Embrapa	Belém
9-Algodual	coast	Coast
10-Maçarico	coast	Coast
11-Atalaia	coast	Coast
12-Pântanos	coast	Coast
13-Ajuruteua	coast	
fann 1-5	Tomé-Açu	

transects extending from the Salinópolis lighthouse to the mangrove bridge and occasionally to the westernmost end of the beach. The species list for the river islands combines records from Barcarena (list 2), Cotijuba (list 3), and Mosqueiro (list 4), based on a total of 17 visits. The Belém city species list aggregates observations from various urban and peri-urban locations such as Belém-Marco (list 7), Icoaraci (list 6), and Mangal das Garças Park (list 5). The checklist was complemented by the Embrapa bird list (list 8), integrating it into the overall regional Belém dataset. Marajó Island was visited on five occasions between 1999 and 2008. Observations were made along the PA-154 road corridor between Soure and Salvaterra, covering areas such as Praia do Pesqueiro, Joanes, and Cachoeira do Arari. The water buffalo experimental station (BAGAM) of Embrapa Amazônia Oriental near Soure (list 1) was also visited twice. In Tomé-Açu, a more intensive sampling regime was implemented as part of Embrapa’s “Projeto Dendê” (Kato et al. 2009). Observations were conducted in traditionally managed and enriched oil palm plantations, as well as in young *capoeira* regrowth (2–5 years old). Surveys were carried out at three daily intervals: 07:30–09:00, 13:00–14:30, and 18:00–19:30. In total, 27 observation days were distributed across five different farms in the vicinity of Tomé-Açu and Quatro Bocas.

All data underpinning the analysis reported in this paper are deposited at GBIF and are available at <https://doi.org/10.5061/dryad.v41ns1sbf>.

Data processing

To evaluate avian diversity and composition across different spatial scales, study locations were categorized into two hierarchical levels (Table 1): (1) site-level (n = 14), comprising individual farms and specific coastal or urban

locations, and (2) regional-level ($n = 4$), representing aggregated inventories of the rural Bragantina, Belém area, Tomé-Açu, and Coast.

For the site-level analysis, species accumulation curves were calculated for the first 30 field days at each location to ensure comparability (Fig. 3). Differences in community composition among these sites were evaluated using non-metric multidimensional scaling (NMDS) with the Bray–Curtis dissimilarity index (Fig. 4).

For the regional-level analysis, complete species inventories were compared against two historical reference datasets: the rainforest avifauna of Belém (Forrester 1993) and the savanna avifauna of Maranhão (Oren 1991) and São Luís (Forrester 1993). This comparison was visualized using NMDS based on Jaccard presence–absence data (Fig. 5).

To better understand the drivers of community differentiation, the total Sørensen dissimilarity (β_{sor}) was partitioned into two additive components, namely true species turnover (β_{sim}), representing the replacement of species between sites, and nestedness-resultant dissimilarity (β_{sne}), representing species loss where one community is a subset of another (Baselga 2010). This

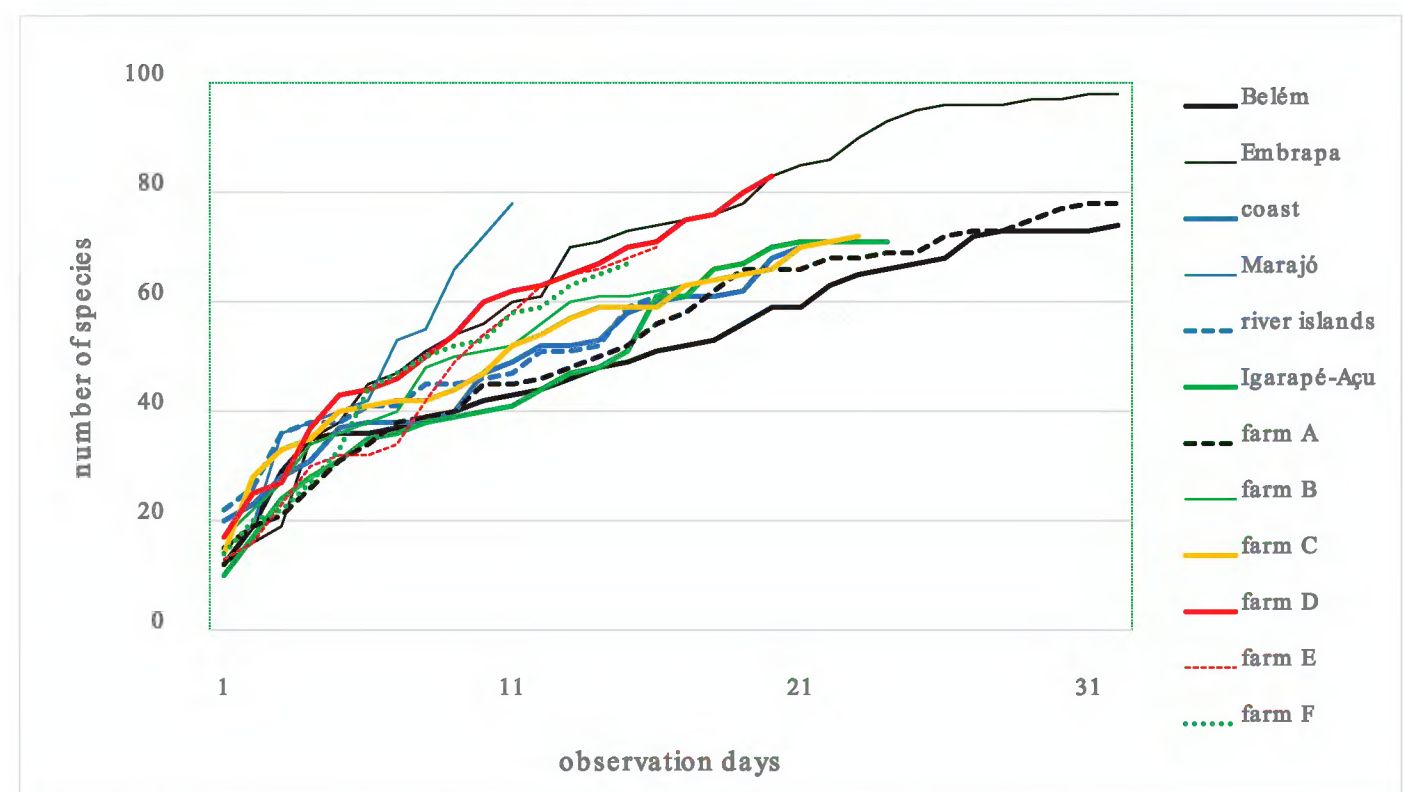


Figure 3. Number of bird species at the respective locations during the first 32 observation days.

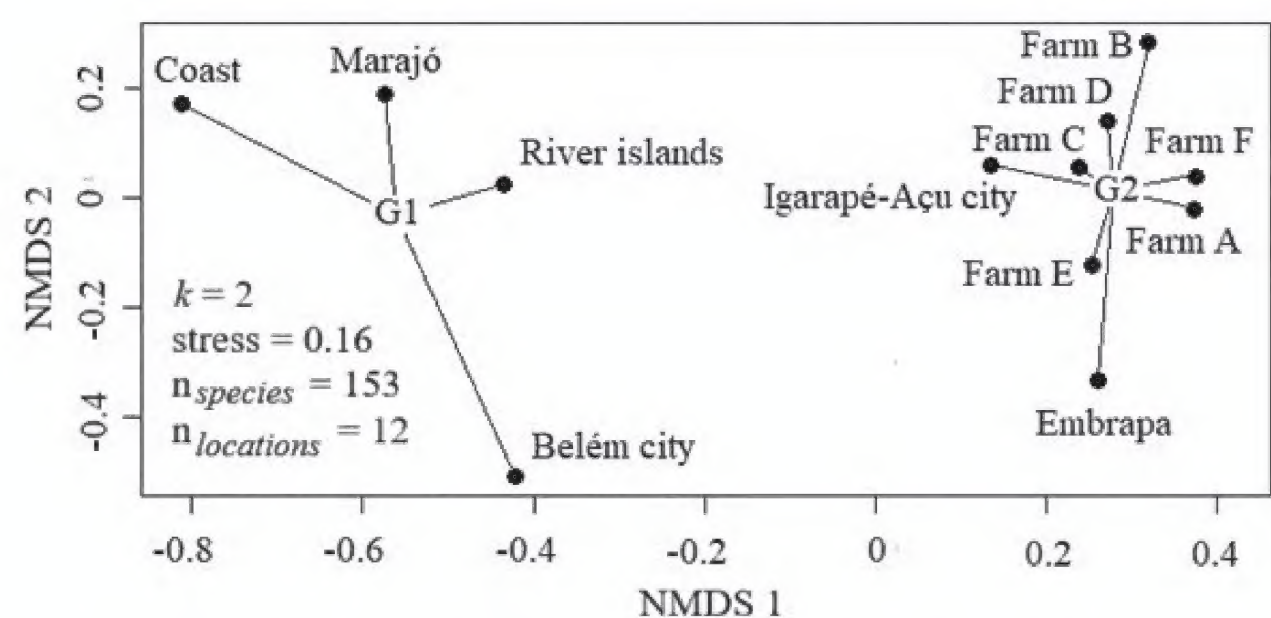


Figure 4. Similarities among the different Bragantinian bird species lists, calculated by NMDS.

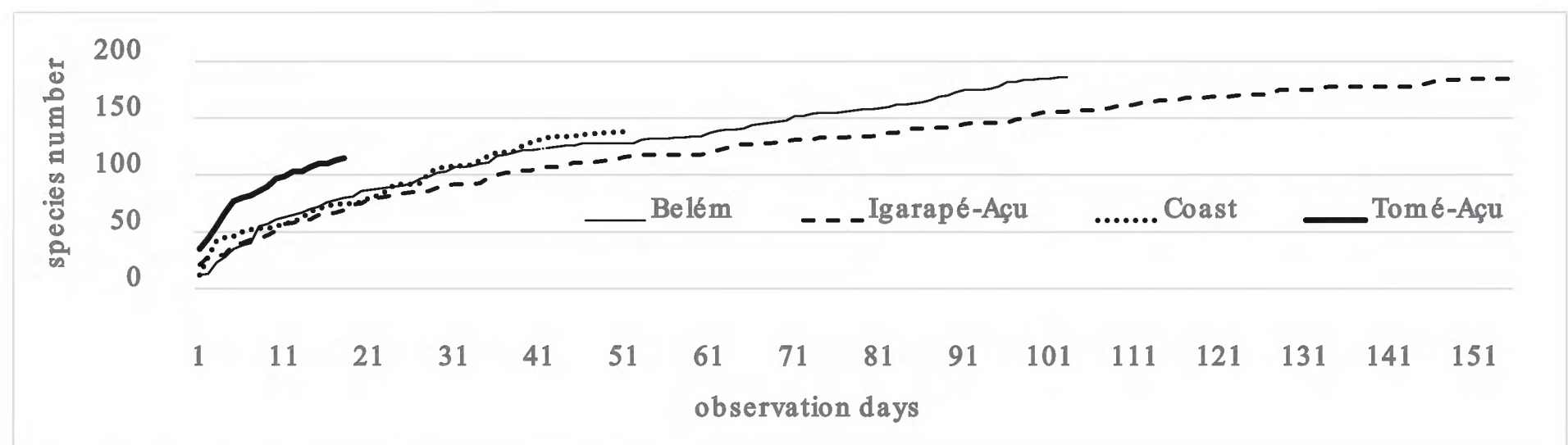


Figure 5. Bird species accumulation curves of the total examined regions.

analysis was performed using the “betapart” package in R, comparing the historical rainforest reference Bragantina (*Bel* list in Forrester 1993) with the current rural landscape of Igarapé-Açu and Belém (Fig. 6).

To evaluate avian diversity across the study regions, the framework of Hill numbers (effective number of species) was employed, which provides a unified approach to quantify diversity at different sensitivity levels to species abundance (Chao et al. 2014). Diversity was calculated for three orders of q : species richness ($q = 0$), Shannon diversity (exponential of Shannon entropy, $q = 1$), and Simpson diversity (inverse Simpson index, $q = 2$). Since the data consisted of species occurrences over multiple sampling units (days), the incidence-raw approach was used. To account for differences in sampling effort and to allow for robust comparisons, the iNEXT package in R (Hsieh et al. 2016) was used to generate integrated rarefaction and extrapolation (R/E) curves. Confidence intervals of 95% were computed using a bootstrap method (200 replications) to determine statistical significance between sites.

Results

Species accumulation curves exhibited a steep ascent during the initial eight to ten observation days, followed by a slower yet consistent increment until the twentieth observation day (Fig. 3). Subsequently, most curves converged toward saturation, oscillating between 60 and 80 species. This pattern is characteristic of forest-cleared landscapes in the Humid Tropics (Hohnwald 2021). The Marajó curve constituted an exception, showing a more rapid development and seemingly failing to reach saturation after the twelfth observation day. The curves for the rainforest locations (Embrapa terrain and Farm D) stabilized at a level that was consistently 20 species higher than the remaining sites.

Species composition comparisons after 32 observation days indicate a division into two main groups (Fig. 4): G1 encompasses sites along both saline and freshwater coasts, including the Belém city peninsula, which is significantly distinct from the other included locations. In contrast, species lists of G2, representing the rural Bragantina region, demonstrate remarkable homogeneity, despite variations in the number of observation days across sites. The Embrapa list, though geographically very close to Belém city, is definitively aligned with these rural locations. The relative isolation of Belém city and Embrapa downward in the figure might be attributable to the higher number of observation

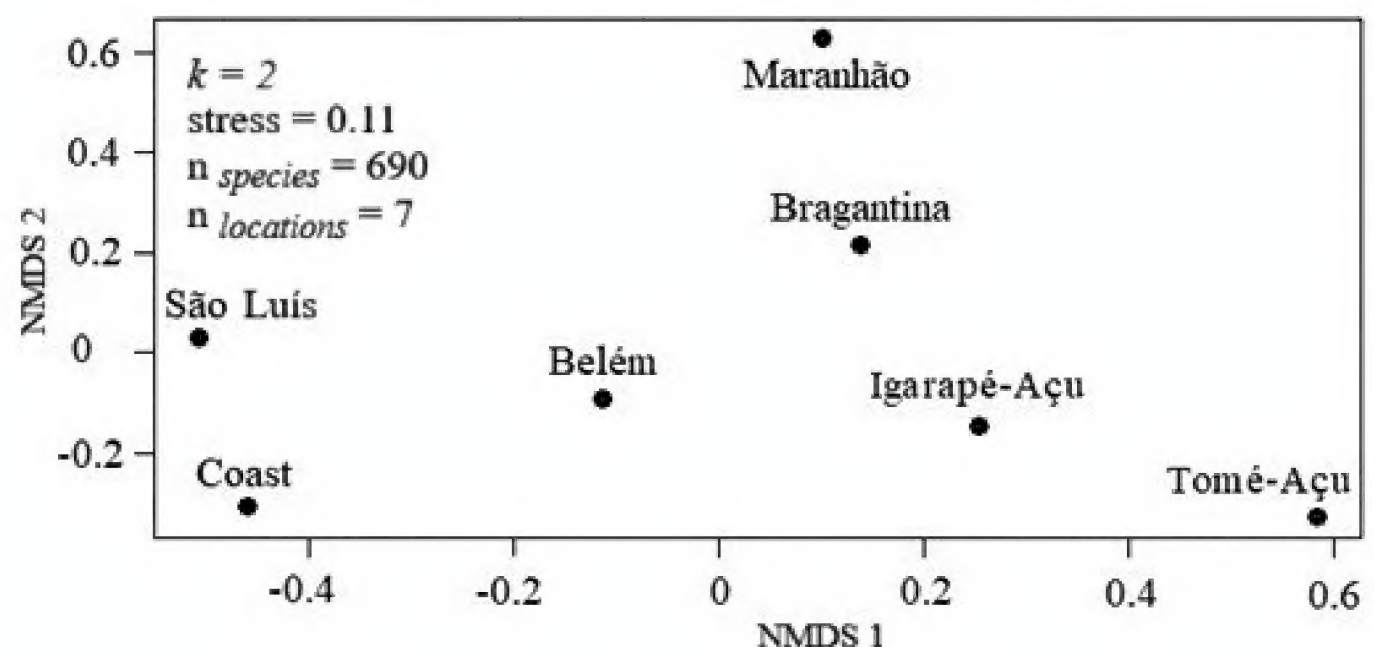


Figure 6. NMDS of the originally collected data of this study (Belém, Coast, Igarapé-Açu, Tomé-Açu) in comparison with three complete species lists of the past (São Luís and Bragantina according to Forrester 1993 [Bel list]; Maranhão according to Oren 1991).

days (Fig. 3). The ordination was restricted to two dimensions ($k = 2$), which achieved an acceptable stress value of 0.16. Convergence was reached within the standard iteration limit, ensuring a stable and robust representation of the ecological distances between sites.

When considering the complete regional species lists (Fig. 5), the accumulation curves do not exhibit saturation at the 80–100 species level but instead maintain a gradual increase up to approximately 180 species. This trend is characteristic of species-rich regions in the Humid Tropics, such as rainforests, where a low detection probability for widely distributed, low-abundance species necessitates a prolonged observation period (Hohnwald 2021). Notably, the Tomé-Açu curve displays a steeper trajectory and a distinct inflection point, a pattern likely explained by a more intensive registration methodology. Despite covering diverse habitats (beaches, mangroves, and estuarine environments), the Coast curve shows surprisingly congruent growth rates with the Belém area. After 50 observation days, however, Coast exhibits the highest species richness among all four total species lists.

Fig. 6 illustrates that the assembled avian Igarapé-Açu and Belém data exhibit a closer affinity to the rainforest biome of the Bragantina of Forrester (1993) than to the savanna biome of Maranhão or São Luís. Interestingly, the Bragantina data show almost equal similarity among Maranhão, Belém, and Igarapé-Açu. Also, the Belém data exhibit correspondence with the historical Bragantina dataset while simultaneously maintaining equal affinities with both Igarapé-Açu and the Coast sites. The Coast sites demonstrate the strongest relationship with São Luís, a correlation likely driven by the shared occurrence of waterfowl. The inventory-based NMDS included a total of 690 species across seven regional and reference lists. The ordination achieved a stress value of 0.11 with $k = 2$ dimensions, using Jaccard dissimilarity for presence–absence data.

In total, 300 bird species were reconfirmed, encompassing 220 genera and 62 families. While no species detected is classified as “Globally Endangered,” *Primolius maracana* is designated as “Vulnerable” (Stattersfield and Capper 2000; IUCN 2024). This species was recorded across ten distinct farms/sites in the central Bragantina, spanning the area from Salinópolis to Castanhal,

specifically at farms A, B, C, and E in the vicinity of Igarapé-Açu, and at the northern locations of farms B, F, and D (Fig. 2).

A single individual of *Guarouba guarouba*, listed as “Vulnerable” in Pará (SEMA 2024), was discovered at the Embrapa facility (10–15 August 2007). This individual was observed attempting to join a flock of *Aratinga jandaya*, though it was largely rejected. A high-flying *Fregata magnificens* was detected migrating westward above Maçarico Beach on 15 September 2007. On 25 March 2007, a little shy, brown *Stercorarius* cf. *parasiticus*, with blunt rectrices, landed on the beach of Salinópolis–Maçarico (species list 10). A *Picumne* specimen (*Picumne* cf. *spilogaster*), distinguished by a striped breast, reddish forehead, and a pale bill, was photographed in the mangroves of Algodoal on 19 August 2007 and on the Embrapa terrain (June 2008; Fig. 7). Additional sightings included a male *Colaptes melanochloros* at farm E on 2 August 2007. *Harpagus diodon* (1 August 2007) and *Spizaetus tyrannus* (27 July 1999) were identified near Igarapé-Açu and farm A, respectively. Three individuals of *Melanerpes candidus* were documented at farm B (Maracanã municipality) on 29 November 2007, a pair at farm D (north of Igarapé-Açu) in June 2006, and several individuals on two farms near Tomé-Açu. A pair of *Stilpnia cayana* were observed breeding adjacent to a farmhouse near Cachoeira do Arari (9 December 2000; Fig. 2). Up to 13 individuals of *Podager nacunda* were documented at farm D (SE location). Finally, *Gallinago paraguaiae* and *Tringa solitaria* were observed at the latter site several times utilizing small puddles (5–50 m²) in pastures for foraging.

The partitioning of beta diversity between the Belém reference and the Bragantina revealed a total dissimilarity of $\beta_{sor} = 0.320$. This difference was almost equally driven by species turnover ($\beta_{sim} = 0.167$) and nestedness (β_{sne}

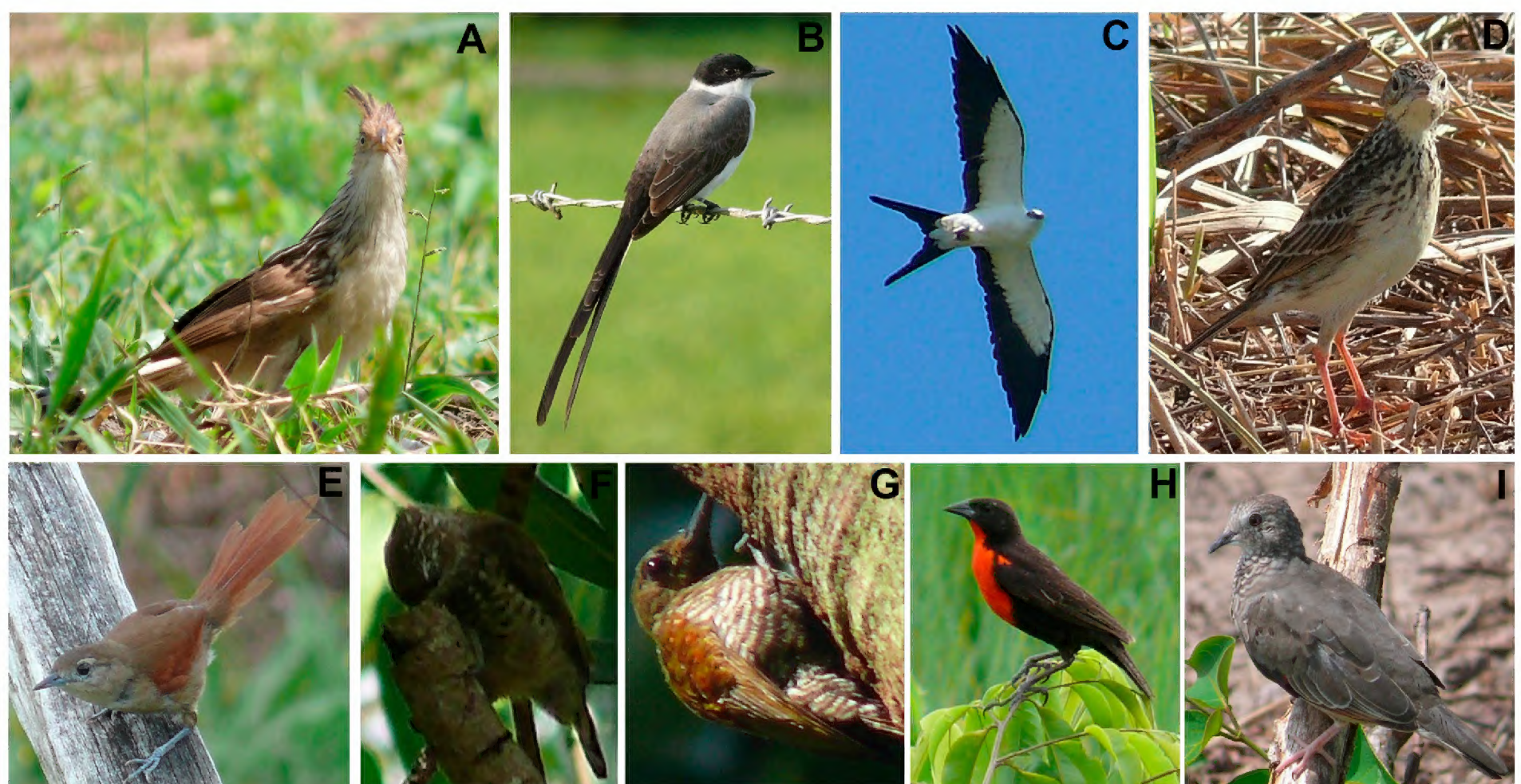


Figure 7. **A.** A hunting *Guiraca guiraca* at the Embrapa Amazônia Oriental, Belém (September 2007); **B.** *Tyrannus savana* (Embrapa, June 2007); **C.** *Elanoides forficatus* (Igarapé-Açu, April 2008); **D.** *Anthus chii* (Igarapé-Açu, June 2007); **E.** *Synallaxis albens* (Embrapa, August 2007); **F.** *Picumne spilogaster* (Algodoal, August 2007); **G.** *Picumne spilogaster* (Embrapa, June 2008); **H.** *Leistes militaris* (Igarapé-Açu, May 2007); **I.** *Columbina passerina* (Igarapé-Açu, May 2007).

= 0.154). In contrast, the comparison within the rural matrix (Igarapé-Açu vs. Bragantina) showed a lower total dissimilarity ($\beta_{sor} = 0.166$), which was almost exclusively attributed to turnover ($\beta_{sim} = 0.160$), with negligible nestedness ($\beta_{sne} = 0.006$).

The iNEXT analysis revealed distinct diversity profiles for the four regions (Table 2). Igarapé-Açu exhibited the highest observed species richness ($q = 0 = 196$), followed by Belém (186). However, when considering the effective number of common species ($q = 1$), the gap between the rural matrix and the forest reference narrowed, suggesting a high turnover of rare species in the anthropogenically modified landscape. The rarefaction/extrapolation curves for all sites approached an asymptote, indicating that the sampling effort was sufficient to capture the majority of the regional avifauna (Fig. 8). Notably, the confidence intervals for Tomé-Açu did not overlap with those of Igarapé-Açu or Belém, confirming a significantly lower diversity in the Tomé-Açu region.

Table 2. Avian diversity profiles across four study regions in the eastern Amazon based on Hill numbers ($q = 0, q = 1, q = 2$). Values represent the effective number of species for species richness ($q = 0$), Shannon diversity ($q = 1$), and Simpson diversity ($q = 2$). Sampling effort is indicated by the number of sampling units ($n = \text{days}$).

Region	$q = 0$	$q = 1$	$q = 2$	Sampling units [days]
	richness	Shannon	Simpson	
Belém	186	148.2	112.5	17
Igarapé-Açu	196	154.5	118.3	22
Coast	138	104.2	82.1	10
Tomé-Açu	121	88.4	64.7	20

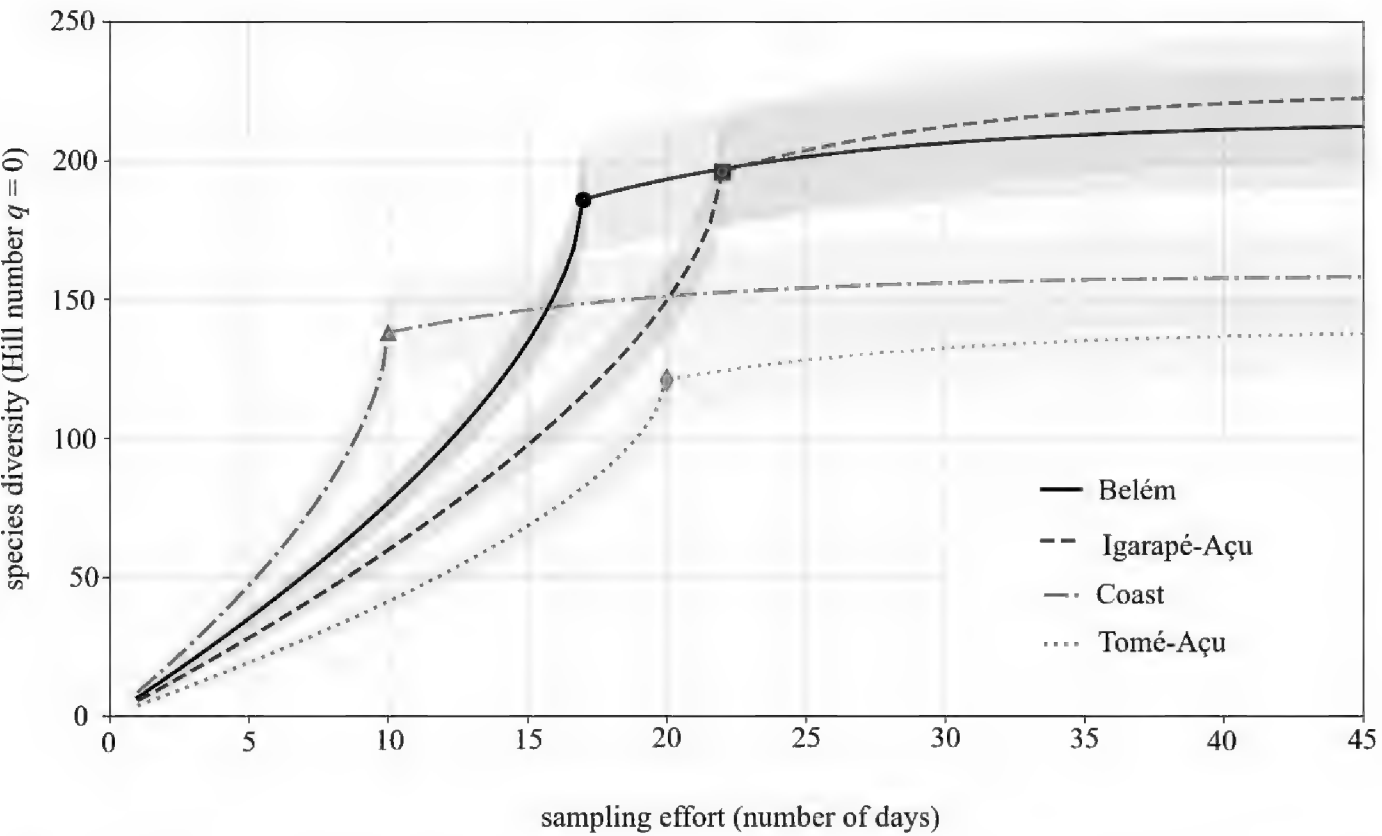


Figure 8. Integrated rarefaction (solid lines) and extrapolation (dashed lines) curves for bird species richness ($q = 0$) across the four study regions. The shaded areas represent the 95% confidence intervals based on 200 bootstrap replications. Points indicate the observed species richness for the actual sampling effort (days). Non-overlapping confidence intervals indicate statistically significant differences in diversity (e.g., between Tomé-Açu and the other regions).

Discussion

This update of the upstate of Belém suggests that the Bragantina region is still more like a rainforest than a savanna biome in terms of bird species composition (Fig. 6). Thus, the hypothesis is rejected: while the landscape has undergone significant transformation, losing its natural closed-forest character and converting to a mosaic of fields, pastures, fallow vegetation, and palm oil plantations (Metzger 2002; Krummel et al. 2008; Hohnwald et al. 2010, 2015), the persistence of a majority of Amazonian baseline species is consistent with a resilient forest-based community. However, the presence of both forest and savanna elements indicates a typical ecotonal character, where rainforest taxa utilize gallery forests and savanna species colonize disturbed areas (de Sousa et al. 2022). The observed reduction in diversity compared to pristine forests (Pacheco et al. 2007; Hohnwald 2021) reflects a predictable shift in community structure. The absence of large-bodied specialists (e.g., *Neomorphus geoffroyi*, *Tinamus* spp.) points toward the local extirpation of taxa sensitive to long-term habitat fragmentation (cf. Portes et al. 2011; Lees et al. 2012; Moura et al. 2014). Conversely, the presence of resilient forest raptors such as *S. tyrannus* and *P. albicollis*, taxa not previously recorded by Forrester (1993), suggests a degree of habitat recovery or stabilization within the rural matrix.

The balanced contribution of turnover and nestedness to the total beta diversity between Belém and the Bragantina also rejects the hypothesis. While a turnover of 0.167 indicates the arrival of open-habitat species, the nearly equal nestedness component (0.154) confirms that the rural community remains, to a large extent, an ecologically impoverished subset of the original rainforest avifauna. Unlike a complete biome shift, which would be characterized by a dominant turnover component, the high degree of nestedness suggests that the regional environmental filter still favors forest-affiliated taxa, however in a structurally simplified landscape. Consequently, the Bragantina does not yet represent a full-scale savanna ecosystem but rather a “degraded rainforest matrix” that preserves its Amazonian history.

The implementation of Hill numbers and iNEXT curves provides a robust statistical backbone to the NMDS results. While the NMDS showed a clear separation in community composition (the “identity”), the Hill numbers reveal that the Bragantina region (Igarapé-Açu) maintains a high numerical diversity (q_0 and q_1) comparable to the Belém reference. This supports the idea that the rural “Amazon Front Yard” is not necessarily species-poor, but its high diversity is driven by a combination of resilient forest subsets and the influx of generalist species (turnover). The significantly lower diversity values for Tomé-Açu ($q = 0, 1, 2$) highlight that different land-use histories within the same “Front Yard” can lead to drastically different ecological outcomes, further validating the importance of regional-scale monitoring. Interestingly, the high values for q_1 and q_2 in Igarapé-Açu indicate an “even” community. This means that the rural matrix is not dominated by just a few main species but supports a broad assembly of birds, which explains why the NMDS shows such a wide spread while the diversity numbers remain high.

It is acknowledged that the opportunistic sampling approach carries inherent limitations regarding detectability and sampling bias. Cryptic, nocturnal, or non-vocal species may be underrepresented compared to more conspicuous

taxa. However, the extended daily observation windows (07:30–16:00) partially mitigated this by covering multiple activity phases. Furthermore, intentionally, presence–absence data were utilized because traditional abundance counts are prone to significant overestimation error during long-term, non-transect stays on active farmland. While the results provide strong evidence that the region retains a humid tropical identity, these findings should be interpreted as a conservative baseline of the resilient avifauna rather than a complete census of all transient or rare species.

Signals of “savannization” are primarily evident through the colonization by open-habitat specialists. Species such as *M. candidus*, *G. guira* (Fig. 7), and *P. nancunda* act as key indicators of this transition, profiting from the expansion of pastures and disturbed habitats. However, the limited expansion of typical semi-humid tropic species indicates that the regional environmental filter still restricts a full-scale biome shift, maintaining the “Amazonian identity” of the Bragantina region. However, these missing species represent the local extirpation resulting from two centuries of colonization and changing land-use systems in the Bragantina, making them the vulnerable taxa in this scenario of global change.

The absence of deep-forest species could also constitute a sampling artifact, as older forest patches were not systematically surveyed in this study. Given that *terra firme* forests are scarce in the Bragantina, persisting only in limited areas such as the military zone near Peixe-Boi (Fig. 2), larger forest patches are now primarily confined to riparian/gallery forest strips (Krummel et al. 2008). Consequently, the presented species lists may primarily capture the most common and readily detectable species within an impoverished, degraded rural landscape, a condition widely observed across Latin America (Novaes and Lima 1992; Hohnwald 2009, 2021).

Another factor contributing to the Bragantina region’s retained Amazonian character is the limited invasion by bird species typically associated with the Semi-Humid Tropics to date. For instance, *Sporophila leucoptera* has only marginally colonized the region. Consequently, dove species frequently found in Maranhão, Piauí, Ceará, and Tocantins, such as *Columbina minuta*, *C. squamata*, *Uropelia campestris*, or *C. picui*, have not yet expanded into the Bragantina. This non-colonization persists despite the presence of extensive open areas that are structurally analogous to the species’ native habitats further east. A similar pattern is observed among several seedeater species, including *Sporophila bouvreuil*, *S. plumbea*, *S. lineola*, and *S. leucoptera*, as well as *Cyanocopsa brissonii* and *Paroaria dominicana* (Thraupidae). These species did not appear even as inner-Brazilian migrants during severe droughts in Northeast Brazil. However, the limited colonization may stem from intrinsic reproductive constraints within the Semi-Humid Tropic populations, potentially limiting the offspring surplus necessary for widespread territorial expansion.

Conversely, endemic canopy species, such as *Xipholena lamellipennis*, *Lipaugus vociferans*, and *Notharchus hyperrhynchus*, might persist within the Bragantina, provided sufficiently large forest fragments and key fruiting tree species are consistently protected or actively planted across the landscape (Nepstad et al. 1996). The isolated, square military rainforest patch near Peixe-Boi serves as a notable positive example (Fig. 2).

Results indicate that the “Amazon Front Yard” operates as a potent ecological filter. The observed turnover reflects a non-random replacement process

where canopy-dependent specialists and large-fruited frugivores are filtered out by structural simplification such as savannization. Conversely, functional resilience is maintained by species capable of navigating the agricultural mosaic, particularly using riparian corridors, *capoeiras* of various stages (ages), and agroforestry homegardens as vital refugia. Unlike pristine Amazonian centers, conservation in the Bragantina should therefore shift from a species-centric approach toward maintaining landscape-level connectivity, as in other regions of Latin America (Walentowski et al. 2018; Hohnwald 2021). Promoting a heterogeneous matrix of *capoeira* successions and forest fragments is crucial to prevent further biotic homogenization and to preserve the region's unique ecotonal character.

Certain registered bird species are likely escaped aviary specimens. For instance, *Gymnomystax mexicanus* and *Zonotrichia capensis* were detected in the vicinity of the Mangal das Garças Park aviary. It is noteworthy that the latter species, a common neotropical generalist, was recorded only twice in the entire study region and time (at the park and near Tomé-Açu). Similarly, the single *G. guarouba* observation is likely attributable to an escaped bird. The closest known breeding population occurs in extensive fragments of dense ombrophilous forest within the Agropalma Group Forestal Reserves and adjacent Turi-Açu farms, located approximately 120 km SSW of Belém (Silveira and Belmonte 2005; Portes et al. 2011). However, *G. guarouba* has demonstrated reproductive activity in degraded rural landscapes similar to the Bragantina at Goianésia do Pará and Breu Branco (Silveira and Belmonte 2005). Therefore, the potential for this species to establish a self-sustaining population in the NE-Amazon warrants future investigation. The documentation of *C. melano-chloros* near Tomé-Açu is also significant, as the species was previously presumed absent from the region, with confirmed populations restricted to Marajó and Maranhão (Mata et al. 2006; IUCN 2024). Frequent observations of *Tham-nophilus aethiops*, classified as "Endangered" by SEMA (2024), around Tomé-Açu supports the findings of Portes et al. (2011), who also reported this species as "common" in the region, suggesting a tolerance for habitat degradation.

P. maracana is globally classified as "Vulnerable" due to rapid population decline driven by habitat loss, degradation, and exploitation (Snyder et al. 2000). The isolated island population of Northeast Pará (Juniper and Parr 1998; Stattersfield and Capper 2000) requires critical reassessment within this context. However, the documentation of large flocks (up to 34 individuals; Hohnwald 2009) and the regular observation of pairs throughout the Igarapé-Açu municipality in this study provides encouraging evidence for the population's stability within the region.

Within the coastal avifauna of the *Salgado paraense*, many of the most common 323 species listed by Lees et al. (2014) were reconfirmed. The observation of *F. magnificens* on 15 September 2007 (and other photos from 2013) predates the earliest recently documented record for Pará (reported on 2 February 2013, with another sighting on 10 September 2010). This collective evidence suggests that frigatebirds are rare transient visitors to the Bragantina coastline. Similarly, the sighting of *S. cf. parasiticus* on 25 March 2007 is significant, as jaegers were generally unrecorded in northern Brazil prior to 2013. Lees et al. (2014) later reported a flock of at least ten jaegers from Salinópolis in late

January 2013, marking the first confirmed state record. The observation in this study therefore constitutes a precedent-setting earlier record.

A taxonomic conundrum remains concerning the genus *Picumnus* on the NE-Pará coast. However, the *Picumnus* specimen observed on Algodoal was identified as a male of *P. s. pallidus*, based on comparisons with existing literature (Mata et al. 2006). The observed *Aramides mangle* sighting is highly likely to be part of the northernmost population, occurring over 11 years prior to the four individuals reported from the same location in 2011. The three observations of *Sternula antillarum* align with that by Lees et al. (2014) for species occurrence between May and July. The aggressive behavior noted during the late May observation suggests potential breeding activity at the westernmost outpost of Maçarico Beach.

Conclusion

Land-use change is a constant and dynamic process within the rural Bragantina landscape, primarily driven by fluctuating market prices for various agricultural commodities (Metzger 2002; Hohnwald et al. 2010, 2015). Given that avian species are characterized by high fidelity to their ecological niches but also possess the mobility to quickly track environmental shifts, the bird community composition within these agro-ecosystems is presumed to be as dynamic as the land-use patterns themselves. Unfortunately, the absence of local bird monitoring groups means that these ecological dynamics currently remain hidden and undocumented in the Bragantina. Consequently, the mechanisms by which certain species successfully keep pace with landscape shifts in this “Amazon Front Yard” present a compelling and necessary focus for future scientific inquiry. While the high intensity of our on-farm observations provided a robust overview of the resilient avifauna, it is acknowledged that the lack of standardized detectability corrections means that shy and rare forest specialists might be underrepresented in this dataset. A significant barrier to local conservation is the lack of access to natural heritage knowledge for smallholders. Residents, despite expressing interest in the region’s birdlife (personal communications), are underserved by a paucity of Portuguese-language field guides and other freely accessible nature information (Souza Filho 2013). However, these community members are critical stakeholders for effective conservation in the region. Their stewardship of the surrounding environment, when informed by conservation science, can ensure that the rural landscape remains a resilient reservoir of neotropical biodiversity, and a well-cultivated “Front Yard” can be full of the amazing Amazonian biodiversity with many positive surprises.

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Additional information

Conflict of interest

The author has declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

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The author solely contributed to this work.

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Data availability

All of the data that support the findings of this study are available in the main text and at <https://doi.org/10.5061/dryad.v41ns1sbf>.

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